Economic Analysis of New Waste Prevention and Recycling Programs

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This paper briefly describes two economic models used to produce the recommended new waste prevention and recycling programs in Seattle's 2011 Solid Waste Plan. The first is the Recycling Potential Assessment (RPA) Model which is a model that forecasts tonnages and financial costs and benefits. The second is Measuring the Environmental Benefits Calculator (MEBCalc™) model used to calculate the environmental benefits from the same set of programs.

Recycling Potential Assessment (RPA) Model Summary

Seattle Public Utilities uses the Recycling Potential Assessment (RPA) Model to

- forecast waste generation
- calculate estimates of tonnages that can be diverted from landfill due to recycling, waste reduction and composting
- provide financial cost and benefit estimates for each of the scenarios analyzed in the model

The purpose of this section is to give a summary of the design of the RPA and how it works.

Model Definitions

The RPA model actually consists of two separate RPA models: one for the municipal solid waste (MSW) stream and one for the construction and demolition debris (C&D) waste stream. The MSW and C&D RPA models are structured very similarly, so this overview is written generally to apply to both models. There is a slight difference between the two models, since in C&D we have beneficial uses as well as recycling. The differences will be pointed out as the models are described.

The waste streams are defined, not so much by the materials that are included in them but in the method and location of disposal. Waste collected from within Seattle, and taken to transfer stations and transferred into containers for transportation to the MSW landfill in Arlington, Oregon, is considered MSW waste (or "garbage"). The waste collected separately under the C&D collection contract--destined for disposal in a C&D landfill--is considered C&D waste.

On the other hand, recycling tonnages are credited to either the C&D sector or the MSW sector depending on the recycled material. For example, any recycled wood waste is counted towards the C&D recycling rate. Plastic film is counted towards the MSW recycling rate, even though plastic film occurs in both the C&D and MSW waste streams. The material accounting is handled in this fashion because, in a lot of cases, the recycling reports SPU uses to track recycled materials are not specific enough for us to tell where the material ***would have been*** disposed (in a C&D vs MSW landfill) had it not been recycled.

Four Modules

Four main modules comprise the RPA model: Waste Generation, Recycling Tonnages, Cost Module and Reporting Module.

Waste Generation Module

The first step in the RPA model is to forecast the amount of waste generation in Seattle, broken down into three sectors for the MSW model (Residential Single Family and Multi-Family, Commercial and Self Haul). The C&D model just has one overall sector. The forecast estimate equations use econometric techniques and include a variety of economic, demographic, price and weather variables.

Each forecasted waste stream is then further broken down into 20 material types, based on the waste stream composition data Seattle regularly collects. The model forecasts waste generation, by sector by material, out 30 years.

Recycling Tonnages Module

The next step is the recycling module, which contains data about existing programs and assumptions about new programs.

Existing recycling and composting programs are modeled based on how much they are currently diverting (the existing recovery rate). Detailed recycling data is collected on a regular basis for programs such as the Seattle's curbside recycling program (which is implemented under a contract with Seattle). Daily "truck level" data is available for total tons collected for each program, and periodic recycling composition data is used to separate the tons collected into the material detail. For other programs, such as most of the commercial recycling (which is collected privately), tons recycled come from an annual report all recyclers in Seattle are required to submit as part of their business license renewal. These reports have annual tons collected by material.

New recycling programs are modeled using judgment as to the ultimate recovery rate a program is projected to achieve, and the "ramp" (or path) the program follows from the time is starts until it reaches a steady recovery rate. The model is set up to run "scenarios," which are groups of programs that are assembled according to some overall themes or scenario descriptions. A base scenario typically models existing recycling programs (without any new programs). Other scenarios then layer on top of the base existing programs.

For each new program, parameters are developed that include what sector and material the program will address, the year the program starts and the new program's ramp. When a new program is included in a scenario that targets the same material that an existing program does, the new program has available to it what remains after the existing program is attributed its tonnages. For example, we have a curbside organics program that diverts food waste, and if we then want to model a program that makes the food waste mandatory, the tons attributed to the new mandatory program are the additional tons diverted after the existing program tons are calculated.

Financial Costs and Benefits Module

The next step in the model is to calculate program costs and financial benefits. The calculations use the factors in the waste generation and recycling tonnages modules just described.

For **program costs**, each program can be modeled using a variety or types of costs. The intention is to model program costs at a detailed enough level so that as program recovery rates are varied, costs will vary in a meaningful way. Programs can have fixed and/or variable cost components. The variable components can vary by household, employee, or tons. Programs can also have capital costs, and the life of the capital can be set to reflect what makes sense for that program's capital types. Examples of typical program costs are: costs of collection, bin or cart cost, education, and processing costs.

The **financial benefits** of recycling include costs we do not have to incur—which is the cost to have recyclable material handled as garbage and disposed in a landfill. When we recycle, tons of material are diverted from garbage and no longer need collecting, transferring, hauling to the rail head, and landfilling. There are savings at each step of the way and these savings are the direct financial benefits to recycling. These are often described as "avoided costs".

In order to calculate these benefits, the model needs to have, as inputs, the variable part of the cost to collect, transfer, transport and dispose of the MSW or C&D. Not all of the costs of collecting a ton of garbage are saved when the ton is diverted to recycling. Only the part of the costs that vary with tons is saved. For example, the variable part of the residential collection cost is calculated based on SPU's collector contracts. Contractors are reimbursed for collection based on a formula that has fixed and variable components. When tonnages vary, we can estimate the effect on the contractor payment using the formula in the collection contract. (The formulas in the contract were developed to try to reflect the reality of how collection costs are accrued. There are large fixed costs associated with collection, including the trucks and the costs to weekly drive by each household, for example. The variable portion of the costs is small for collection since the truck must pass by the household each week, regardless of the amount of waste that is put out for disposal.)

Similarly, we have transfer station and haul cost models which we use to determine the variable portion of these two functions. Finally, disposal costs are considered to be 100% variable with tons. This is because for MSW we have a long-term contract where we pay a per-ton fee for rail haul and disposal, and the fee does not depend on how many tons are delivered.

The cost model uses the above information in the calculation of the financial benefits of recycling. (A second group of benefits, the environmental benefits of recycling, are handled outside of the RPA model and will be described in the next section.) The result of the cost model is the additional costs of adding the recycling program (which include education, collection, any capital costs, processing, etc), and the benefits (or avoided costs) of not having to collect the material for disposal in a landfill.

Reporting Module

The final module in the RPA model is simply used to develop reports so detailed results of each model run can be presented as needed. Results reported include displaying the tons recycled by year by material and by program. Reports also show the recovery rate for each material by sector, and an overall recycling rate. The C&D model shows a second rate, that we call the "beneficial use" rate. This rate includes tons that are diverted from disposal to be used for energy production or landfill cover. The report tables following this write-up are examples of the reports generated by the reporting module.

Environmental Benefits to Recycling

Beginning with the 2004 Plan Amendment "On the Path to Sustainability" SPU has been estimating a series of external benefits to recycling. This section describes the steps used to model these external benefits. We start by introducing some background on the methodology, followed by more detail on how environmental benefits are quantified. The results of applying the methodology are shown in the 2 charts placed at the end.

Introduction

Handling and disposal of waste causes external environmental costs and benefits. Externalities are impacts on the environment that are not "counted" in the price (cost) of the activity.

For example, using recycled instead of virgin feedstock to manufacture paper, aluminum cans or tin cans creates measureable environmental benefits. Many of these benefits are from reduced energy use in the production process and associated avoided emissions. There are also measureable benefits of diverting organics from landfills. Landfilled organics produce methane, a powerful greenhouse gas. We have been working over the past couple of years to be able to both quantify and monetize these benefits.

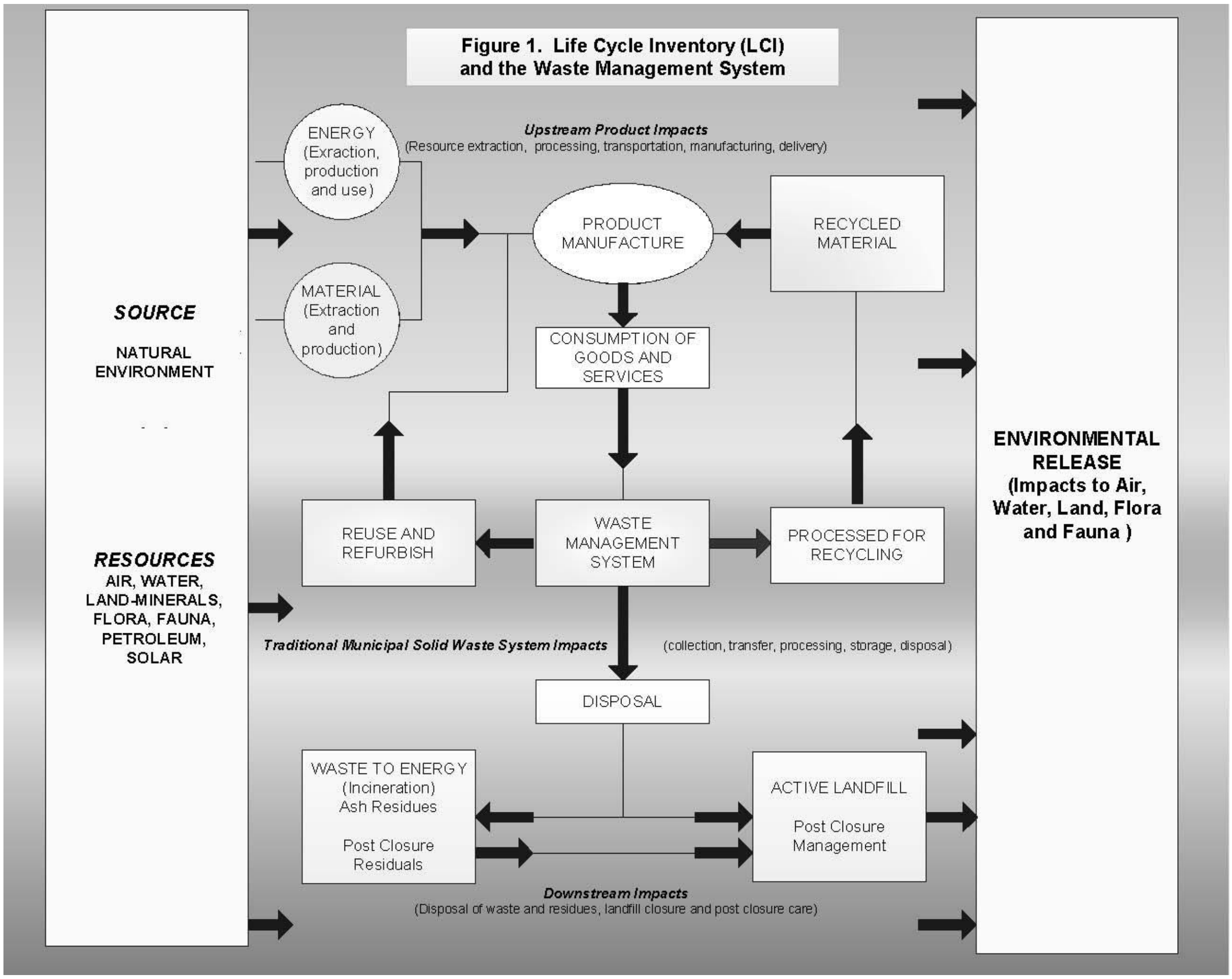
There has been extensive research in the area of quantifying these external benefits over the past 25 years. An important early research initiative was a seminal study done by the Tellus Institute (Tellus Institute, The Council of State Governments, US EPA, and New Jersey Department of Environmental Protection and Energy, *CSG/Tellus Packaging Study: Assessing the impacts of production and disposal of packaging and public policy measures to alter its mix*, May 1992). This study examined both the upstream effects of using recycled material versus virgin material in the production of new products. It also looked at the downstream effects of additional trucks on the streets, and reduced materials at landfills.

The US EPA has extensive information on their website on this topic (e.g., see http://www.epa.gov/osw/conserve/rrr/recycle.htm). EPA also funded the development of a solid waste planning tool, the MSW Decision Support Tool (DST), which optimizes on cost, recycling percentage or levels of pollution (see http://www.epa.gov/osw/nonhaz/municipal/pubs/ghg/f02024.pdf).

SPU has used the DST tool, and upstream effects information provided in the database that supports the tool, to examine the externalized costs of some of its recycling programs.

SPU now uses the MEBCalc™ tool to estimate and quantify the environmental value of recycling programs. This tool takes into account the environmental costs of collection, processing and hauling activities needed for recycling. These environmental costs are deducted from the environmental benefits of producing products using recycled rather than virgin feedstocks.

The following graphic illustrates material flow and the types of externalities associated with the life cycle of materials.



How External Benefits Are Quantified and Monetized

Going from the tons of a variety of recycled materials to a dollar value of the environmental benefit involves a series of steps. First, recycled/composted tons, by material, are taken from the outputs of the RPA Model. Then a variety of tools and databases (described below) provide information on quantities of pollutants that are not produced when material is recycled or composted instead of being thrown away.

For example, manufacturing a new aluminum can using a recycled can uses less energy--which results in the release of fewer pollutants due to the lower energy requirement. Less pollution means lower public health and other environmental impacts from producing the aluminum can. Based on the costs that pollution causes for public health and the environment, we then can calculate the cost savings from making the aluminum can out of a recycled can rather than newly mined bauxite and other virgin raw materials.

Large numbers of pollutants are reduced for each of the life cycle environmental impacts (described below) for all of the recycled and composted materials. This is handled by using one pollutant as an index for each of these impacts. The most familiar example is CO2 used as the index for global warming. If methane is one of the pollutants reduced due to recycling or composting, this is expressed in units of C02. All the other pollutants that contribute to global warming are also expressed in units of CO2, and this allows them to be added together. Hence the term CO2 equivalents. The next step is then to place a value on (i.e., monetize) the reduction in CO2. This step of monetization allows all the life cycle impacts to be summarized in dollars, and added onto the financial costs and benefits of recycling calculated in the RPA model.

The current status of the art of quantifying external environmental benefits provides monetary values on at least 7 different types of environmental impacts. This allows us to represent some of the upstream savings when material is recycled instead of disposed. The next section describes the 7 damages (impacts) we have valued, followed by a discussion of other impact categories and benefits not quantified.

Life Cycle Impact Categories: Short Description & Estimates of Impact Cost

The following descriptions of the 7 impact categories, or indices, are based on Jane Bare, TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0, *Clean Technologies and Environmental Policy*, 2011 13(5) 687-696. This article provides additional detail on environmental impact categories. The 7 impact categories include

1. ***Global warming potential***
2. ***Acidification potential***
3. ***Eutrophication potential***
4. ***Respiratory Human Health Impact Potential***
5. ***Non-Cancer Human Health Impact Potential***
6. ***Cancer Human Health Impact Potential***
7. ***Ecological toxicity potential***

1. Global Warming Potential

This index characterizes greenhouse effect increase due to emissions generated by humankind. Life Cycle Analyses (LCAs) often use a 100-year time horizon to frame the global warming potential of greenhouse gases. For example, carbon dioxide (CO2) from burning fossil fuels to generate energy is the most common source of greenhouse gases. Methane from anaerobic decomposition of organic material is another large source of greenhouse gases. The index often used for global warming potential from greenhouse gas releases is quantities of CO2 equivalents.

Estimates of the dollar cost of a ton of greenhouse gases, measured as CO2 equivalents, range quite widely. At the low end, an estimate could be based on prices for emissions permits traded under voluntary greenhouse gas emission limitation agreements, which hover around $1 per ton CO2. A high-end estimate could be based on the $85 per metric ton cost developed in Nicholas Stern, *The Economics of Climate Change: The Stern Review*. Cambridge and New York: Cambridge University Press, 2007. There are even higher estimates for the cost of carbon emissions. However, for this evaluation we used $40 per ton of CO2 emissions.

2. Acidification Potential

This index characterizes the release of acidifying compounds from human sources, principally fossil fuel and biomass combustion, which affect trees, soil, buildings, animals and humans. The main pollutants involved in acidification are sulfur, nitrogen and hydrogen compounds – e.g., sulfur oxides, sulfuric acid, nitrogen oxides, hydrochloric acid, and ammonia.

There are economic benefits of recycling due to reductions in the releases of acidifying compounds. These reductions are due to decreased reliance on virgin materials in manufacturing products. is The index often used for acidification potential is sulfur dioxide (SO2) equivalents.

One impact cost estimate (of releases of acidifying compounds) is provided by the spot market price for SO2 emissions permit trading under the Clean Air Act's cap and trade program. EPA's spot market auctions for emissions permits for the years 2005 through 2010 averaged $410 per ton SO2. We used this valuation for reductions in releases of acidifying compounds.

3. Eutrophication Potential

This index characterizes the addition of mineral nutrients to soil or water. In both media, adding large quantities of mineral nutrients (such as nitrogen and phosphorous) results in generally undesirable shifts in the number of species in ecosystems, that is, a reduction in ecological diversity. In water, it tends to increase algae growth, which can lead to low oxygen, causing death of species such as fish.

There are economic benefits of recycling associated with the resulting reductions in releases of nutrifying compounds. This decreased release is due to decreased reliance on virgin materials in manufacturing products. For eutrophication potential, the index often used is quantities of nitrogen (N) equivalents.

Our estimate of the impact cost of releases of nutrifying compounds is based on EPA's cost-effectiveness analysis for the NPDES regulation on effluent discharges from concentrated animal feeding operations. That analysis estimated that costs up to $4 per ton of nitrogen removed from wastewater effluents were economically advantageous. (*Economic Analysis of the Final Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent*

Guidelines for Concentrated Animal Feeding Operations, EPA-812-R-03-002, December 2002, p. E-9.)

4. Respiratory Human Health Impact Potential

Criteria air pollutants are solid and liquid particles commonly found in the air. These include coarse particles known to aggravate respiratory conditions such as asthma, and fine particles that can lead to more serious respiratory symptoms and disease. The particular criteria air pollutants that cause these human health effects are nitrogen oxides, sulfur oxides, and particulates.

We denominated this impact category in PM2.5 equivalents (particulate matter no larger than 2.5 microns). A mid-range estimate of the human health costs of PM2.5 emissions is $10,000 per ton, as discussed in Eastern Research Group, *Draft Report: Cost Benefit Analysis for Six "Pure" Methods for Managing Leftover Latex Paint - Data, Assumptions and Methods,* prepared for the Paint Product Stewardship Initiative, 2006.

5. Non-Cancer Human Health Impact Potential:

Under the Life Cycle Initiative of the United Nations Environment Program (UNEP)/Society of Environmental Toxicology and Chemistry (SETAC), various international multimedia model developers created a global consensus model—USEtox—to address an expanded list of substances which might have impacts on human health cancers and non-cancers, as well as on ecotoxicity. The USEtox model adopted many of the best features of these developers' models, and yielded human health cancer and non-cancer toxicity potentials, and freshwater ecotoxicity potentials, for over 3,000 substances including organic and inorganic substances. EPA uses these potentials in its TRACI 2.0 software (*Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts*).

The economic benefits of recycling include reductions in releases of compounds toxic to humans. These toxic reductions are due to decreased reliance on virgin materials in manufacturing products. Tons of toluene is used as the human toxicity potential index.

As discussed in Jeffrey Morris and Jennifer Bagby, Measuring Environmental Value for Natural Lawn and Garden Care Practices. *International Journal of Life Cycle Assessment,* 2008, 13(3) 226-234, a mid-range estimate of $118 per ton of toluene equivalents is a reasonable estimate to monetize non-cancer human health impacts caused by substances such as mercury, toluene and acrolein.

6. Cancer Human Health Impact Potential:

A mid-range estimate of $3,030 per ton of benzene equivalent releases to air is used to monetize cancer human health impacts caused by emissions of substances such as formaldehyde, benzene and mercury.

7. Ecological Toxicity Potential:

EPA, in its TRACI 2.0 software, also provides toxicity equivalency potentials that measure the relative potential for harm to terrestrial and aquatic ecosystems from chemicals released into the environment. The estimated cost to ecosystems of chemical releases is $3,280 per ton of 2,4-D herbicide equivalents released to waterways, as discussed in Morris and Bagby (2008). This may be a very conservative cost estimate based on the citation by Eastern Research Group (2006) of remediation costs for 2,4-D removal of $368,000 per ton.

Impact Categories Not Yet Quantified, Material Types Not Yet Evaluated, And Externalized Costs Underestimated

Currently, economic benefits estimates for SPU recycling programs do not include any benefit estimates for several materials such as gypsum wallboard, household batteries, carpet and paint. LCA research is currently underway so that these materials can be included in future calculations of recycling's environmental benefits.

Environmental impact and resource depletion impacts include the following categories that are not presently included in our quantification of benefits. This is due to the absence of emissions data for the specific pollutants tracked under some of these categories, the lack of quantitative measures to relate emissions to impacts, and/or the absence of well-researched monetization estimates:

1. Fossil Fuel Depletion Potential
2. Habitat Alteration Potential
3. Smog Formation Potential
4. Ozone depletion Potential
5. Indoor Air Quality
6. Water Intake

Estimates of damage costs may underestimate the actual costs, to future generations, of current releases of pollutants and depletion of resources. This seems a particularly acute problem for ecosystem impacts, given our currently limited understanding of long run impacts from

- accelerated species extinctions and decreases in biodiversity, and
- associated decreases in various aspects of ecosystems' ability to, among other things, cycle nutrients, clean our air and clean our water.

Future costs from cumulative impacts of global warming are also difficult to predict.

Finally, estimates of human health costs from toxic and carcinogenic releases do not presently appear to account adequately for impacts (cumulative and interactive) of many of the chemical releases to the environment. There may be as many as 75,000 to 100,000 chemical compounds used in industrial processes and commerce.

To put this into perspective, our seven impact categories quantify releases to air and water for less than a thousand substances. The MSW Decision Support Tool (DST) developed under sponsorship of EPA provides full life cycle quantification for releases of just ten air pollutants and seventeen water pollutants. The DST database provides upstream quantification of releases for recycled-versus virgin-content manufacturing (including the extraction and refining stages) for a number of other substances. But even there, the number of tracked substances totals well under 100.

Other Benefits Not Quantified: Existence Value of Recycling

Waste disposal reduction (which lowers the need for landfills), and the conservation of limited resources, are two public goods provided by recycling programs. Within the context of present market mechanisms, the economic value of these public goods is unlikely to be reflected in market prices--and therefore likely to escape benefit-cost assessments of recycling. Consumers who choose to participate in recycling programs may not see the public good benefits from their own recycling (since their contribution is relatively small compared to the total); however, they do obtain benefits from everybody else's recycling efforts. This is a type of non-use (sometimes called existence) value of recycling programs. Likewise, consumers who choose not to participate in recycling programs also enjoy the benefits of these public goods.

Analysis Results for Seattle's Solid Waste Plan Waste Reduction and Recycling Recommendations

The following two charts illustrate the magnitude of the additional benefits from recycling MSW and C&D materials, for both past years and planned future recycling through 2030. These benefits are calculated by first starting with the tons recycled/composted from the RPA model for the recommended scenarios. Then using the techniques described above and embodied in MEBCalc^{TM}, the benefits are quantified across the life cycle impact categories using an indexed pollutant for each category. Then a monetary value is placed on each of the indexed pollutants to allow these different life cycle impact categories to be expressed in dollar terms so they can be added together.

For MSW, Chart 1 shows estimated environmental benefits for actual recycling from 1997 through 2010. For C&D, Chart 2 shows estimated environmental benefits for actual C&D material recycling for 2007 through 2010.Reductions in climate change and human health impacts account for most of the environmental value of MSW recycling. This is a result of diverting materials from disposal to recycling. Most of the environmental value for C&D recycling comes from reductions in human health and ecosystem toxicity impacts, as a result of diverting C&D materials from disposal. For the years 2007 through 2010, and a few years following 2010, reductions in climate change impacts also provide a substantial portion of the environmental benefits for C&D recycling.

Chart 1 Environmental Value ($millions) of Recycled MSW Tons. 1997-2030

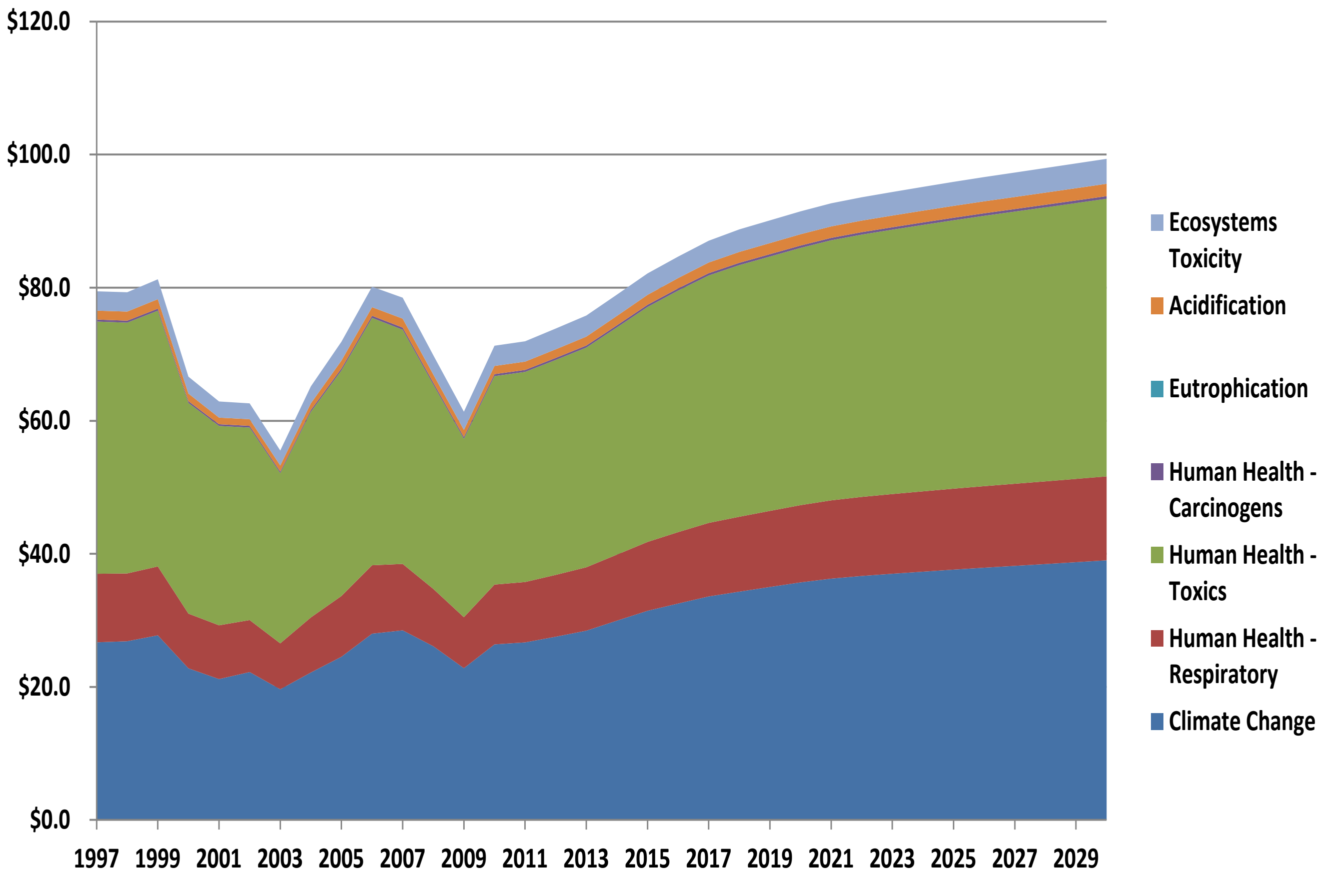


Table 1 Environmental Value ($millions) of Recycled MSW Tons*

Year	Climate Change	Human Health - Respiratory	Human Health - Toxics	Human Health - Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Total Environmental Value
2010	26.4	9.0	31.3	0.3	0.0	1.2	3.0	71.5
2020	35.7	11.6	38.7	0.4	0.0	1.7	3.4	92.9
2030	39.0	12.6	41.7	0.4	0.0	1.9	3.8	101.0

*Monetized Value of Specific Environmental Impacts Reductions

Chart 2 Environmental Value ($millions) of Recycled C&D Tons, 2007-2030

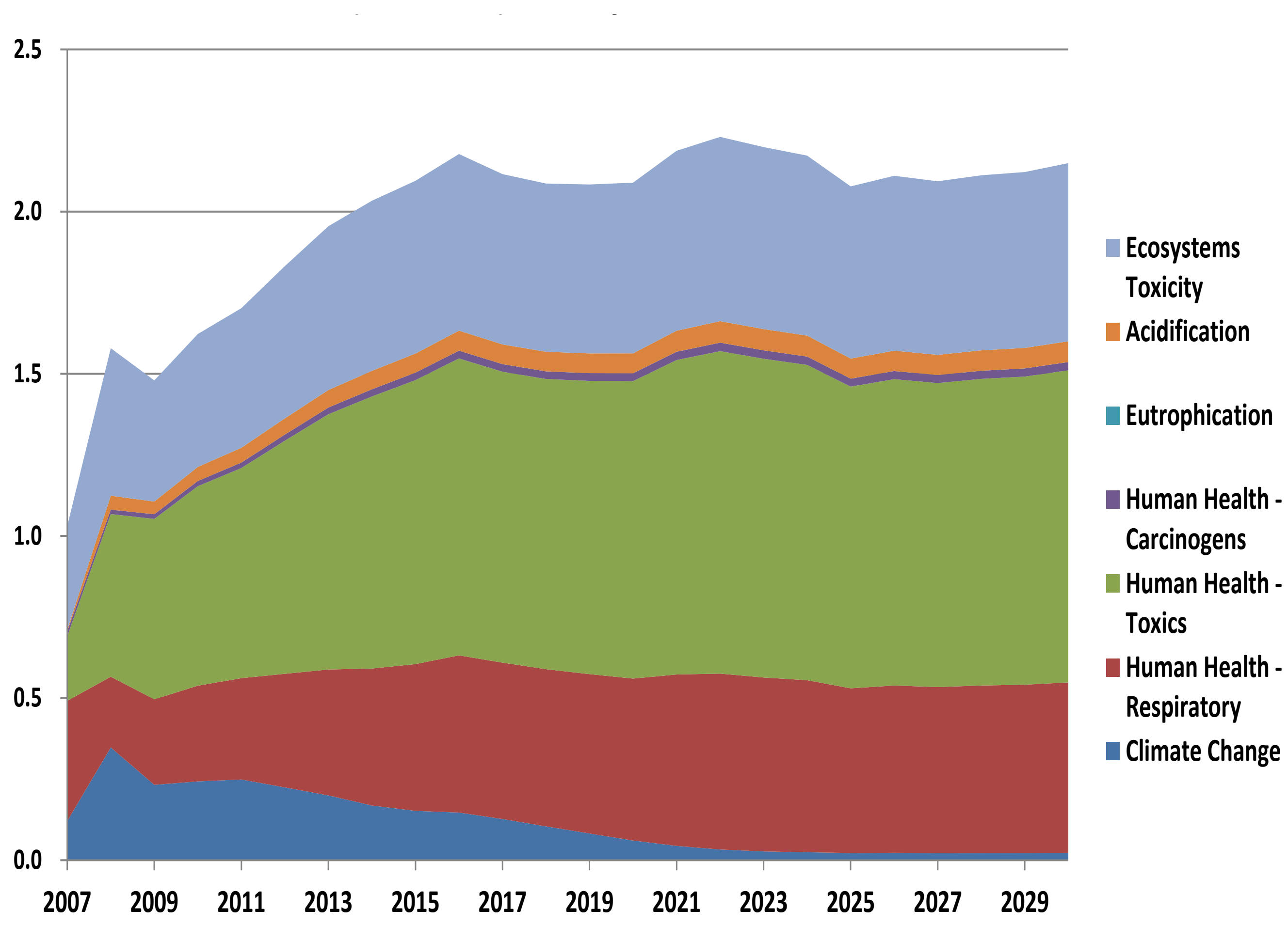


Table 2 Environmental Value ($millions) of Recycled C&D tons*

Year	Climate Change	Human Health - Respiratory	Human Health - Toxics	Human Health - Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Total Environmental Value
2010	0.243	0.295	0.615	0.016	0.000	0.043	0.410	1.623
2020	0.060	0.500	0.918	0.024	0.000	0.062	0.526	2.090
2030	0.023	0.525	0.963	0.025	0.000	0.064	0.550	2.150

*Monetized Value of Specific Environmental Impacts Reductions